A GEOSTATISTICAL STUDY FOR GEOLOGY - ENERGY - MINERAL RESOURCES IN THE CALIFORNIA DESERT

MAIN REPORT

TERRADATA

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Submitted to:

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ABSTRACT

A geostatistical analysis of Geology-Energy-Minerals (G-E-M) resources in the California Desert Conservation Area (CDCA) was undertaken. The CDCA comprises over 107,000 square kilometers in southeastern California. All available reports of G-E-M occurrences in the CDCA were collected. Data on the 3,009 occurrences include location, commodity, name and, in some cases, geologic environment and production. Forty geological variables represented on the Geologic Map of California, and one geophysical variable (Bouguer gravity) were recorded on a cell-by-cell basis over the entire CDCA. Data were encoded in numerical form for 26,810 cells (2 km by 2 km square). Data recorded in this fashion, plus the data on G-E-M occurrences, served as the basis for statistically classifying cells according to likelihoods of mineral occurrence. Cells so classified are 4 km x 4 km (an aggregate of four of the smaller 2 km x 2 km cells). Since regression analysis proved inappropriate, discriminant function analysis is the principal statistical method used to classify the cells. The cells of the CDCA are classified with respect to the occurrence of gold deposits; iron and manganese deposits; and combined copper, zinc, lead, and silver deposits. Occurrence data on over 40 other mineral commodities including sand and gravel, limestone, carbon dioxide, and geothermal fluid, were tabulated but were not subjected to statistical analysis due to the small amount of occurrence data. Results are presented in tabular form and in map form.

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Reported Mineral Occurrences In The CDCA

Wells (oil, gas, CO_2 and geothermal fluids) In The CDCA

Occurrence And DFA Predictions In The CDCA: Gold

Occurrence And DFA Prediction In The CDCA: Copper-Lead-Silver-Zinc

Occurrence And DFA Prediction In The CDCA: Iron-Manganese

I. INTRODUCTION AND SUMMARY

Section 601 of Public Law 94-579 charges the Bureau of Land Management (BLM) with the preparation of a plan for the multiple-use management of the California Desert Conservation Area (CDCA). This area is approximately 107,000 square kilometers. Its boundaries are shown in Figure 1. Its resources are to be inventoried to generate a multiple-resource data base which will be analyzed and then synthesized into recommendations. Geology-Energy and Minerals (G-E-M) together form one of several groups of resources to be inventoried.

The objective of this study, as one of several in the program developed for G-E-M resource evaluation, is to obtain a "first-cut"classification of the CDCA's potential for energy and mineral resources. Such a classification should be based on analysis of existing lithologic, structural and mineral data plus other pertinent data. The analysis preceeded in three steps.

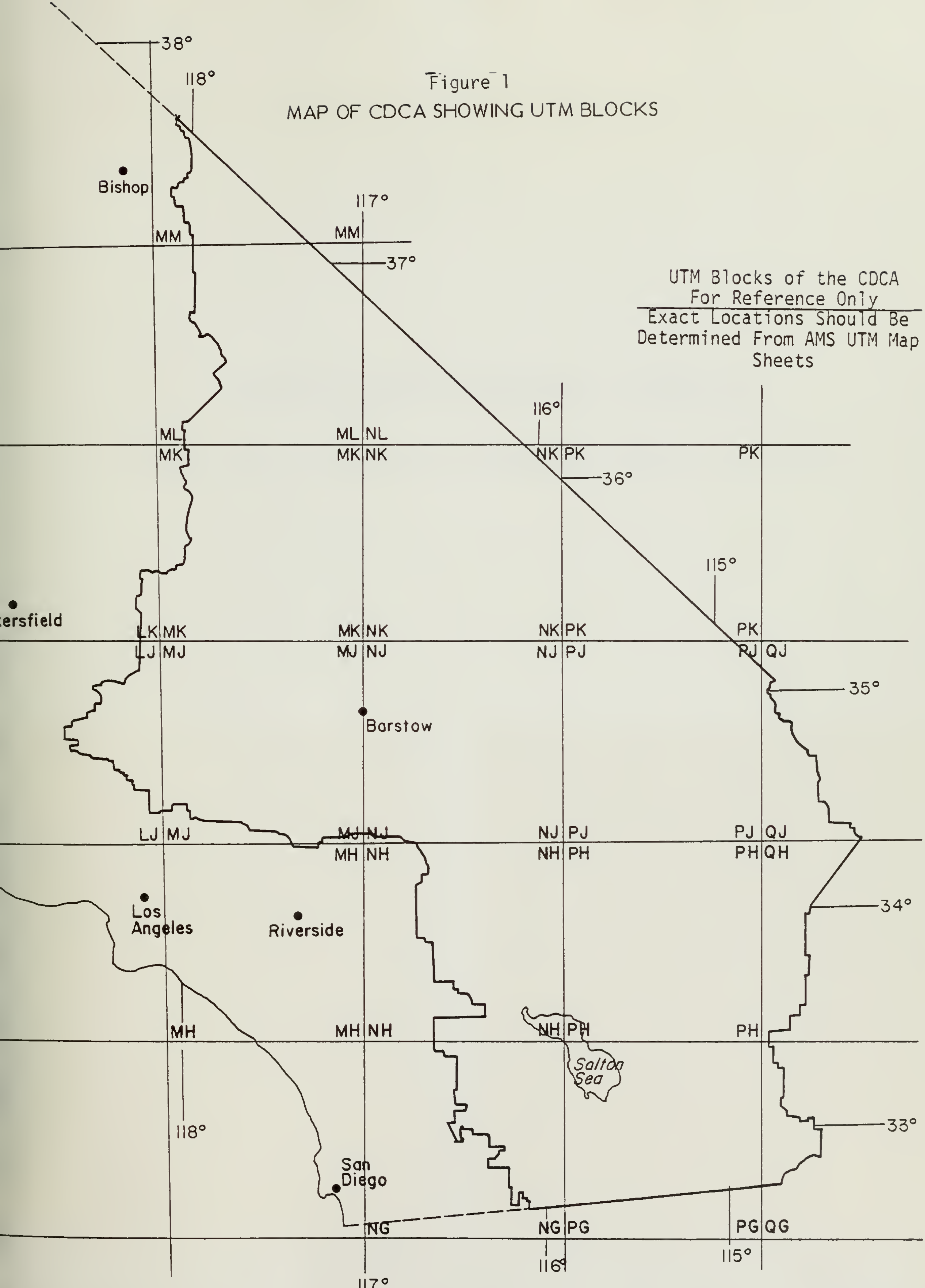
1. Compilation of data
2. Geostatistical analysis
3. Classification of the CDCA as to its potential for G-E-M resources.

The five maps in envelopes following page 2 summarize the results of this study. The maps are as follows:

- Reported Mineral Occurrences In The CDCA
- Wells (oil, gas, CO_2 and geothermal fluids) In The CDCA
- Occurrence And DFA Predictions In The CDCA: Gold
- Occurrence And DFA Prediction In The CDCA: Copper-Lead-Silver-Zinc
- Occurrence And DFA Prediction In The CDCA: Iron-Manganese

Figures 2 and 3 (pages 3 and 4) are flow charts of the analytical process.

Figure 1
MAP OF CDCA SHOWING UTM BLOCKS



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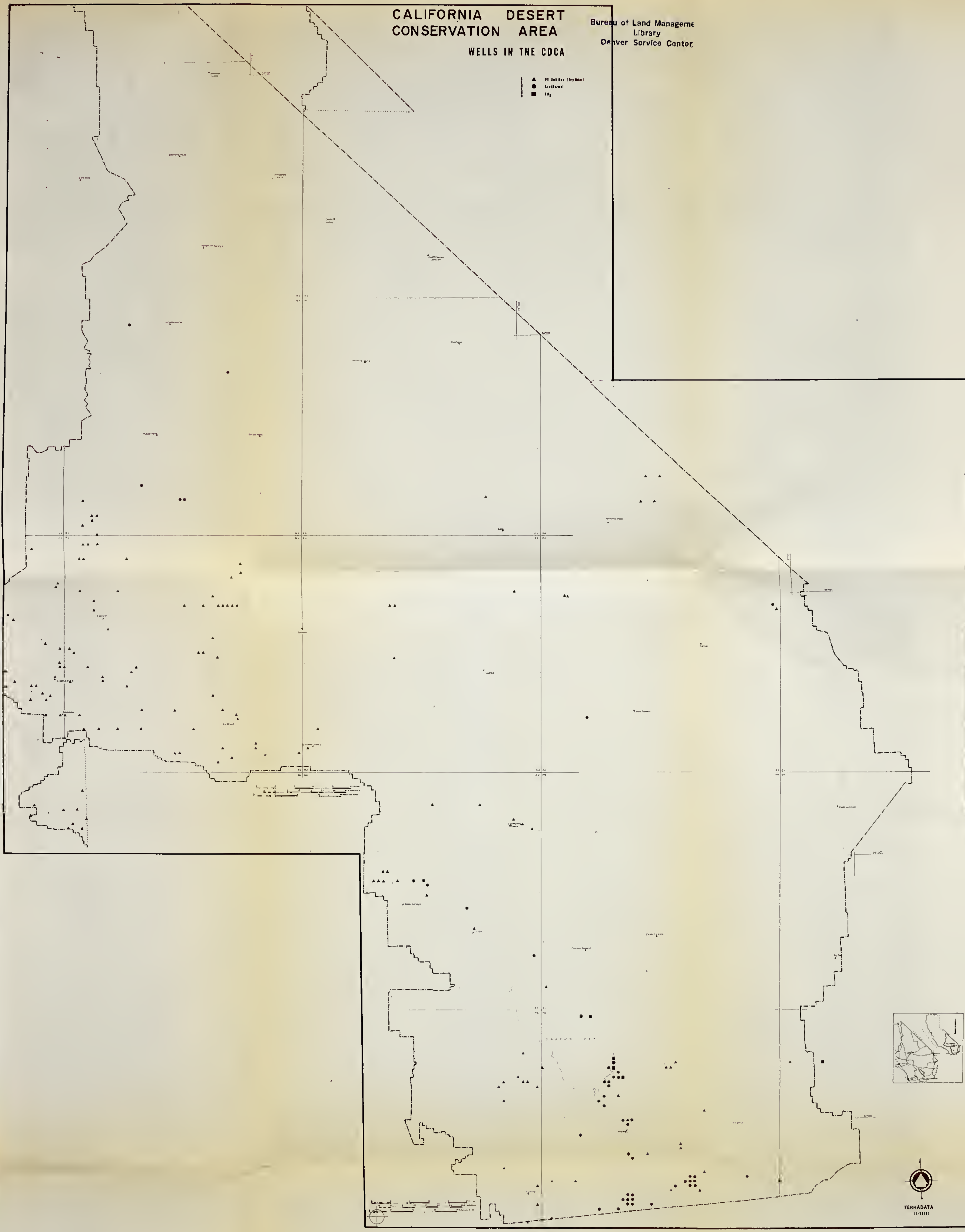
CALIFORNIA DESERT
CONSERVATION AREA
WELLS IN THE CDCA
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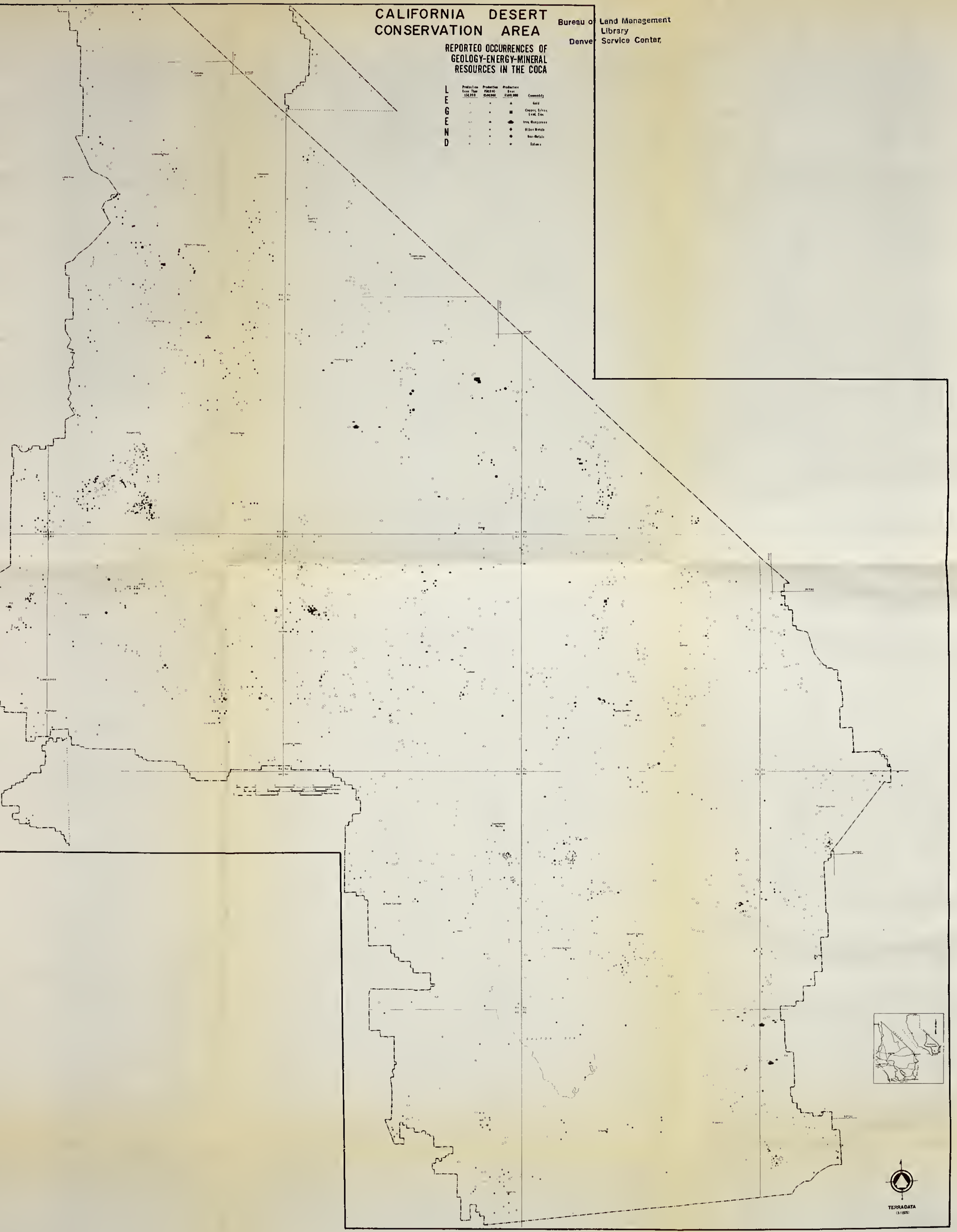
CALIFORNIA DESERT CONSERVATION AREA
REPORTED OCCURRENCES OF GEOLOGY-ENERGY-MINERAL RESOURCES IN THE COCA
LEGEND
Gold
SALTON SEA
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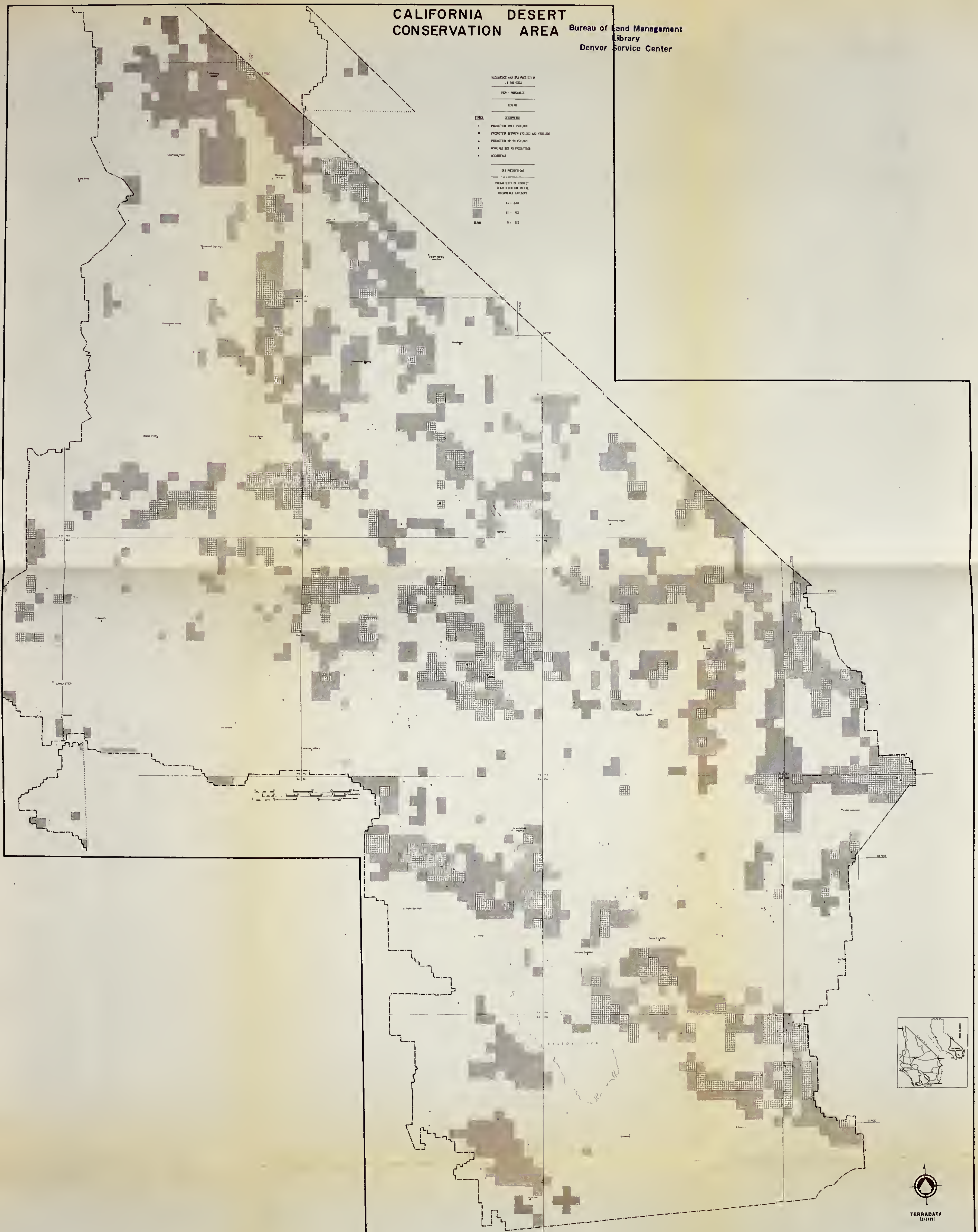
CALIFORNIA DESERT
CONSERVATION AREA
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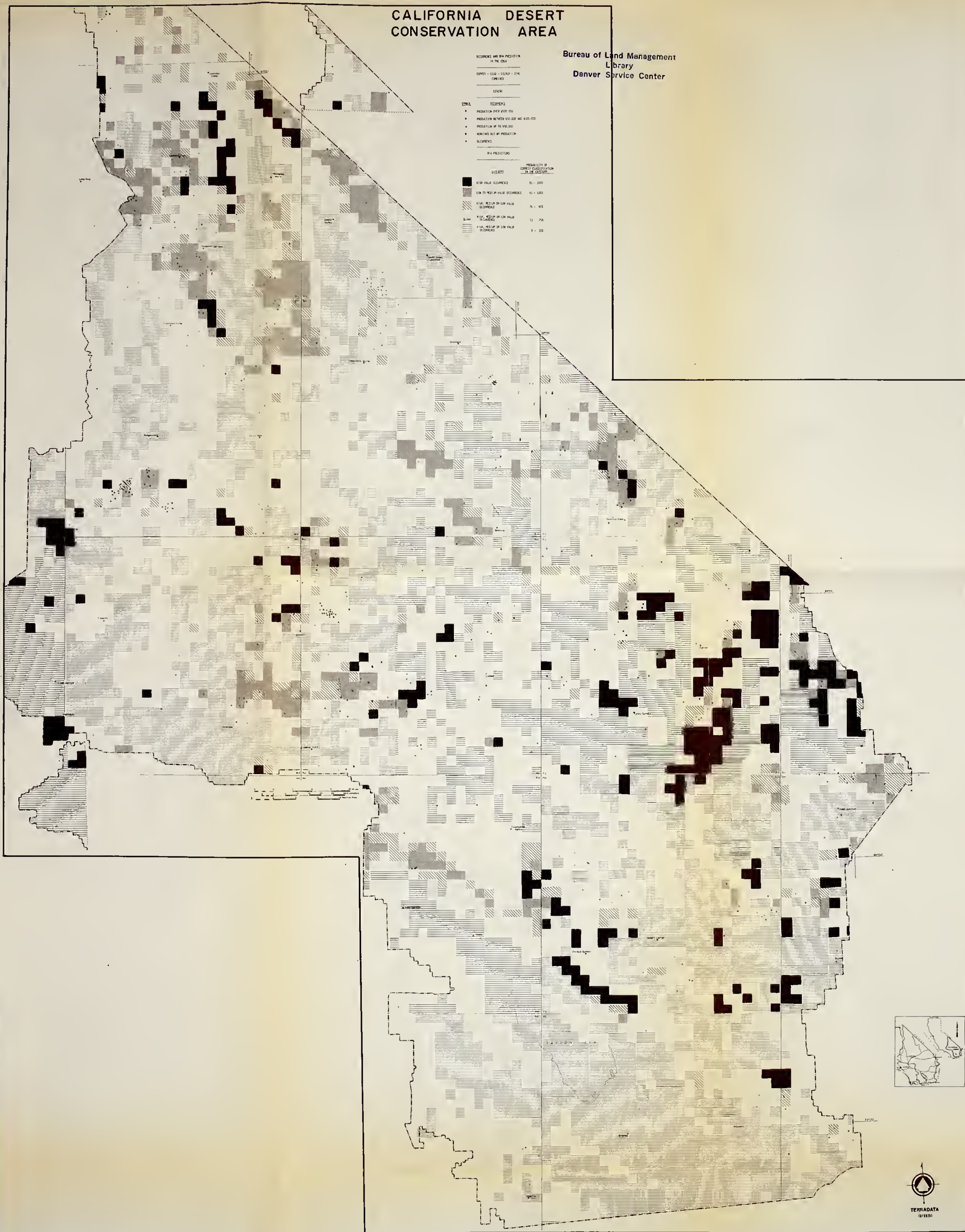
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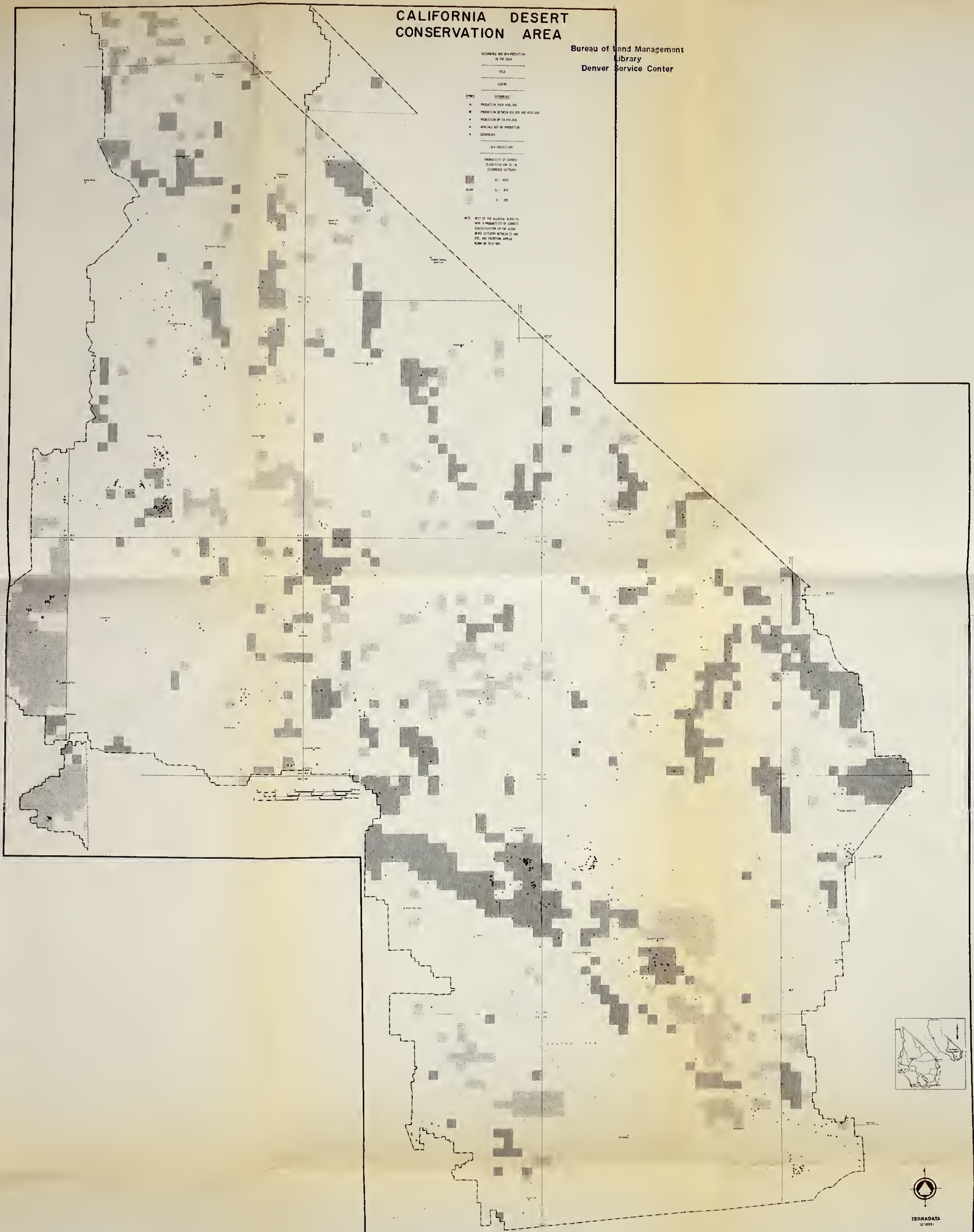
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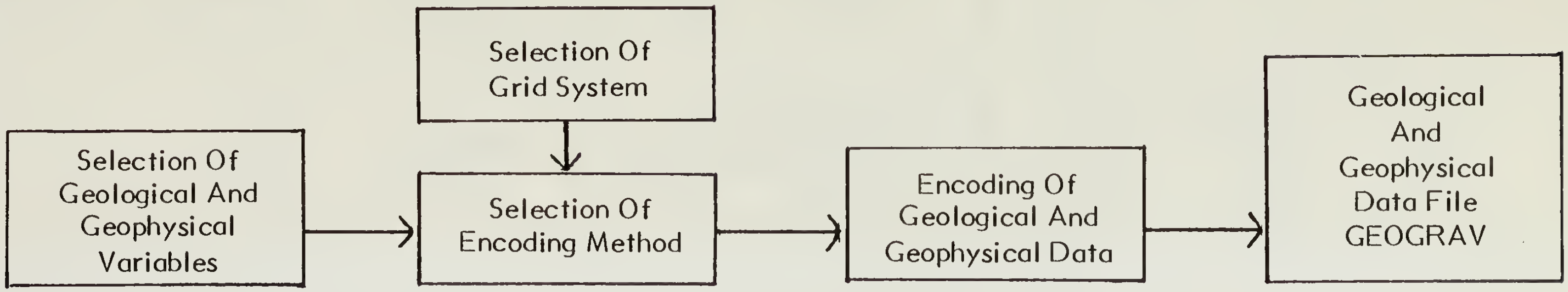
Figure 2

FLOWCHART OF DATA COLLECTION AND PREPARATION

Geological and Geophysical Data



Geology-Energy-Mineral Occurrence Data

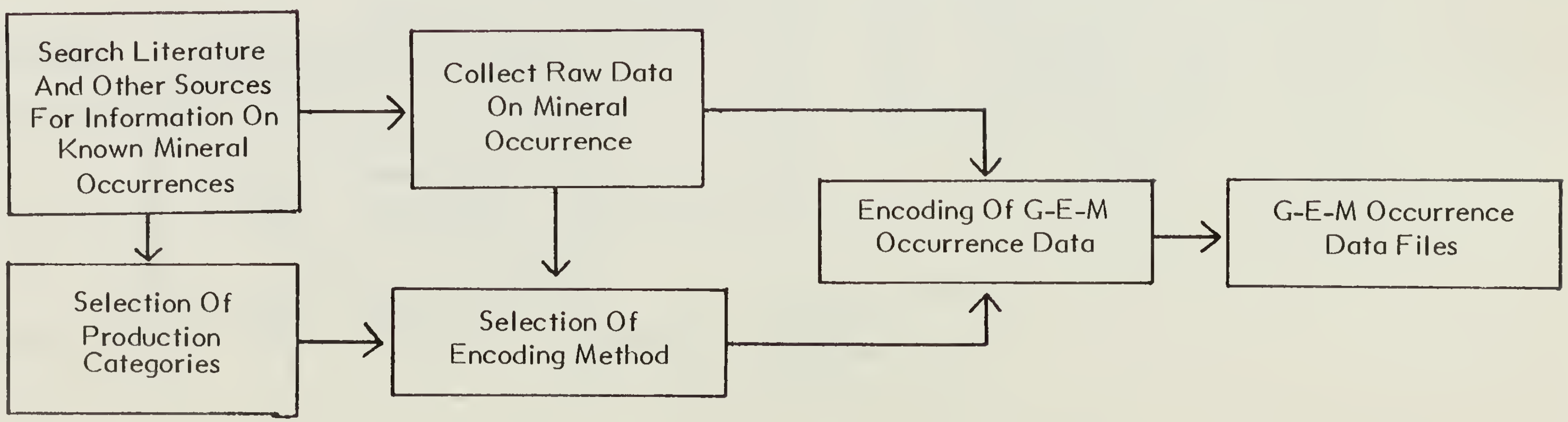
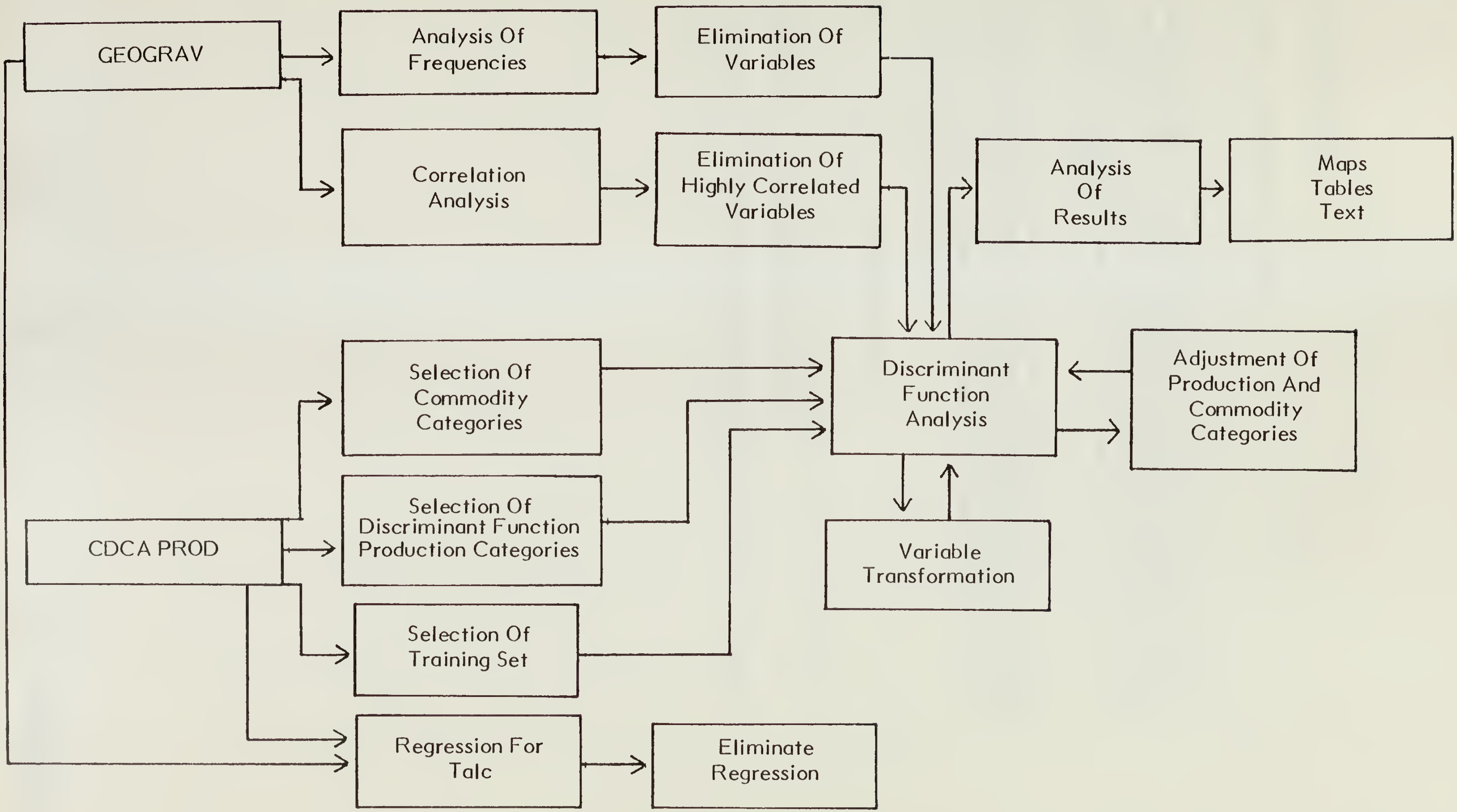


Figure 3

FLOW CHART-GEOSTATISTICAL ANALYSIS



2. DATA COMPILATION

Two types of data were compiled as follows:

1. All known and reported occurrences of G-E-M resources in the CDCA were compiled. A total of 3,009 occurrences of forty-seven G-E-M resources were identified. These occurrences are summarized in Table 1 on page 6. Appendix A presents details on occurrence data and contains 12 maps of mineral occurrence. Sources for these data are shown in Appendix A.

2. Using 2 km by 2 km cells based on the UTM grid system, 40 geological variables were measured on a cell-by-cell basis. Bouguer gravity data were tabulated for 4 km by 4 km cells. These data are summarized in Tables 2, 3 and 4, pages 7-10. Appendix B presents details on the geologic and geophysical data.

This data base thus compiled provides the following:

- The data, when mapped or listed systematically, provide useful information for land-use planning decisions.

- The data form the basis for statistically classifying lands with respect to the occurrence of certain mineral resources.

Table 1

MINERAL OCCURRENCES IN THE CDCA[a]

BY COMMODITY AND PRODUCTION CATEGORY

Commodity	Symbol	Production Category[b] 0	1	2	3	4	Total All Categories
Metals							
Antimony	A	3	5	8	0	0	16
Copper	Cu	86	146	80	12	0	324
Gold	Au	166	400	172	46	22	806
Iron	Fe	29	27	19	1	0	75
Lead	Pb	69	87	46	16	5	223
Manganese	Mn	26	49	21	3	3	102
Mercury	Hg	5	3	1	0	0	9
Nickel	Ni	1	2	0	0	0	3
Molybdenum	Mo	1	1	1	0	0	3
Rare earths	RE	5	7	0	0	1	13
Silver	Ag	5	47	22	2	4	80
Tin	Sn	1	1	0	0	0	2
Titanium	Ti	0	1	0	0	0	1
Thorium	Th	0	1	0	0	0	1
Tungsten	W	30	70	45	3	3	151
Uranium	U	115	15	14	0	0	144
Vanadium	Va	0	1	0	0	0	1
Non-Metals							
Asbestos	As	3	0	1	0	0	4
Barium	Ba	10	7	6	0	0	23
Clay	Cl	13	28	25	5	2	73
Dimension stone	Ds	7	9	18	0	0	34
Feldspar	Fd	8	4	4	0	0	16
Fluorspar	Fl	6	9	3	0	0	18
Gemstones	Gs	22	13	3	0	0	38
Limestone	Ls	48	20	23	2	3	96
Magnesite	Mg	1	9	4	0	0	14
Mica	Mi	3	3	6	0	0	12
Roofing granules	RG	0	1	9	0	0	10
Sand and gravel	SG	39	20	43	12	0	114
Silica	Si	10	1	10	1	1	23
Sulfur	S	1	2	2	0	0	5
Talc	Tc	24	20	11	12	7	74
Volcanic cinders	VC	29	18	18	0	0	65
Wollastonite	Ws	1	1	1	0	0	3
Miscellaneous	Ms	2	2	2	0	0	6
Salines							
Borates	B	35	2	15	2	2	56
Calcium chloride	CC	1	1	3	0	0	5
Gypsum	G	19	7	11	0	1	38
Magnesium salts	MC	1	0	0	0	0	1
Potasium salts	KS	1	1	5	0	0	7
Salt	NC	5	3	10	0	0	18
Sodium carbonate	SC	0	0	4	0	0	4
Sodium sulfate	SS	5	0	2	0	0	7
Strontium	Sr	3	0	4	0	0	7
Total All Commodities		838	1,044	672	117	54	2,725
Wells							
Oil and gas (all are dry holes)							188
Carbon dioxide							8
Geothermal							88
Total Wells							284

[a] Data on hot springs (HS) is included in the data base but has not been tabulated.

[b]
- 0 = Occurrence or claim
- 1 = Worked, but no production reported
- 2 = Small Producer (less than $50,000)
- 3 = Moderate Producer ($50,000 to $500,000)
- 4 = Major Producer (over $500,000)

Table 2

GEOLOGIC AND GEOPHYSICAL VARIABLES FOR THE CDCA

Lithologic Units

Variable Number	Description	Areal Extent Within CDCA (km^2)	% Of CDCA Area
1.	Precambrian granitic rocks. - Precambrian anorthosite. - Undivided Precambrian granitic rocks.	701	0.67
2.	Precambrian metamorphic rocks. - Precambrian igneous and metamorphic rock complex. - Earlier Precambrian metamorphic rocks. - Later Precambrian sedimentary and metamorphic rocks. - Undivided Precambrian metamorphic rocks.	5,542	5.28
3.	Cambrian and late Precambrian sedimentary rocks. - Cambrian and Precambrian marine. - Cambrian marine.	1,963	1.87
4.	Ordovician through Mississippian marine sedimentary rocks. - Ordovician marine. - Pre-Silurian metasedimentary rocks. - Silurian marine. - Devonian marine. - Mississippian marine. - Paleozoic marine.	2,318	2.21
5.	Pennsylvanian through Permian marine sedimentary rocks. - Pennsylvanian marine. - Undivided carboniferous marine. - Permian marine.	489	0.47
6.	Pre-Cretaceous metasedimentary rocks and pre-Cretaceous metamorphic rocks.	1,298	1.24
7.	Paleozoic and Precambrian metavolcanic rocks. - Pre-Silurian metamorphic rocks. - Pre-Silurian metavolcanic rocks. - Devonian and pre-Devonian metavolcanic rocks. - Devonian metavolcanic rocks. - Carboniferous metavolcanic rocks. - Permian metavolcanic rocks. - Paleozoic metavolcanic rocks.	14	0.01

Table 2 (continued)

8.	Triassic-Jurassic marine sediments. - Triassic marine. - Middle and/or Lower Jurassic marine. - Upper Jurassic marine. - Knoxville Formation.	28	0.03
9.	Pre-Cretaceous metavolcanic rocks (if age cannot be established other than pre-Cretaceous). - Pre-Cretaceous metavolcanic rocks. - Jura-Triasic metavolcanic rocks.	472	0.45
10.	Mesozoic basic intrusives. - Mesozoic ultrabasic intrusive rocks. - Mesozoic basic intrusive rocks.	277	0.26
11.	Mesozoic granitic intrusives and pre-Cenozoic granitic and metamorphic rocks.	14,431	13.76
12.	Eolian deposits.	3,271	3.12
13.	Tertiary sediments (marine and non-marine).	2,860	2.73
14.	Tertiary igneous intrusives (hypabyssal).	515	0.49
15.	Tertiary volcanics. - Eocene volcanics. - Oligocene volcanics. - Miocene volcanics. - Pliocene volcanics.	5,142	4.90
16.	Quaternary sediments. - Plio-Pleistocene non-marine. - Pleistocene non-marine. - Pleistocene marine and marine terrace deposits. - Quaternary non-marine terrace deposits. - Glacial deposits. - Salt deposits. - Basin deposits. - Fan deposits. - Stream channel deposits. - Alluvium.	61,815	58.93
17.	Quaternary volcanics. - Pleistocene volcanics. - Recent volcanics.	1,652	1.57
18.	Bodies of water and unmapped areas.	2,112	2.01
	TOTAL	104,900	100.0

Table 3

GEOLOGICAL AND GEOPHYSICAL VARIABLES FOR THE CDCA

Rock Contact Relationships

Variable Number	Description	Total Length In CDCA (Km)
19	Length of contact between Precambrian granitic rocks (1) and Precambrian metamorphic rocks (2).	481.0
20	Length of contact between Mesozoic granitic intrusives and pre-Cenozoic granitic and metamorphic rocks (11), and either Ordovician through Mississippian marine sedimentary rocks (4), or Pennsylvanian through Permian marine sedimentary rocks (5).	565.0
21	Length of contact between Mesozoic granitic intrusions and pre-Cenozoic granitic and metamorphic rocks (11) and Triassic-Jurassic marine sediments (8).	1.6
22	Length of contact between Tertiary igneous intrusives (14) and Precambrian granitic rocks (1).	0.8
23	Length of contact between Tertiary igneous intrusives (14) and Precambrian metamorphic rocks (2).	53.2
24	Length of contact between Tertiary igneous intrusives (14) and Cambrian and late Precambrian sedimentary rocks (3).	3.2
25	Length of contact between Tertiary igneous intrusives (14) and Ordovician through Mississippian marine sedimentary rocks (4).	5.2
26	Length of contact between Tertiary igneous intrusives (14) and Pennsylvanian through Permian marine sedimentary rocks (5).	9.6
27	Length of contact between Tertiary igneous intrusives (14) and pre-Cretaceous metasedimentary rocks and pre-Cretaceous metamorphic rocks (6).	7.2
28	Length of contact between Tertiary igneous intrusives (14) and Paleozoic and Precambrian metavolcanic rocks (7).	2.8
29	Length of contact between Tertiary igneous intrusives (14) and Triassic-Jurassic marine sediments (8).	2.8
30	Length of contact between Tertiary igneous intrusives (14) and pre-Cretaceous metavolcanic rocks (9).	2.8
31	Length of contact between Tertiary igneous intrusives (14) and Mesozoic basic intrusives (10).	4.8
32	Length of contact between Tertiary igneous intrusives (14) and Mesozoic granitic intrusives and pre-Cenozoic granitic and metamorphic rocks (11).	208.0
33	Length of contact between Tertiary igneous intrusives (14) and eolian deposits (12).	0.1
34	Length of contact between Tertiary igneous intrusives (14) and Tertiary sediments (13).	83.0

Table 4

GEOLOGICAL AND GEOPHYSICAL VARIABLES
AND NUMBER OF SUBCELLS
FOR THE CDCA

Structural Relationships

Variable Number	Description	Total In CDCA
35.	Length of thrust faults (km).	518
36.	Number of thrust faults.	415
37.	Length of non-thrust faults (km).	14,907
38.	Number of non-thrust faults.	12,629
39.	Number of fault intersections.	1,889
40.	Curvature of faults.	n/a
41.	Gravity value measured at cell center.	n/a
42.	Number of subcells.	26,812

3. GEOSTATISTICAL ANALYSIS

Three statistical methods were considered for predicting locations of G-E-M resources. These were cluster analysis, multiple linear regression analysis and discriminant function analysis. As discussed in Appendix C, discriminant function (DFA) analysis showed the greatest possibilities for providing useful information. DFA results are presented for three commodity categories—combined silver, lead, copper and zinc; combined iron and manganese; and gold. DFA assigns each 4 km x 4 km cell a likelihood of occurrence of each of the three commodity categories on the basis of geological and geophysical parameters. Care should be exercised when interpreting the results of the discriminant function analyses. Precautions on their use are contained in Appendix C.

4. CLASSIFICATION

The potential for selected mineral resources in the CDCA is classified according to probability of occurrence in the designated categories. The classifications are based upon the location of the known mineral occurrences, plus the DFA results. Each 4 km by 4 km cell has been classified. The results are summarized on the maps following page 2.

5. RESULTS OF DISCRIMINANT FUNCTION ANALYSIS

Three cases of discriminant function analysis were selected as containing potentially useful results. For visual presentation, maps showing the results of the of DFA predictions and reported occurrences for the three cases are contained in the envelopes following page 2. The three cases are:

- Gold
- Silver, Lead, Copper and Zinc combined
- Iron and Manganese combined.

5.1 STATISTICAL INTERPRETATION

DFA calculates from data in the "training set" (i.e., cells with known parameters) one function (two functions when three categories are considered) and two group means (three when three categories are considered) corresponding to each of the pre-defined production categories (e.g., occurrence or no reported occurrence). This function (or functions) is then applied to all cells in the area, the scores are compared to the value of the group means and the cells are assigned to the group whose mean their function score most closely matches. In addition, there is a probability attached to each cell which is a measure of how close that cell's function score is to the group mean. A probability of 100 percent indicates that the score is identical to the mean. A 90 percent probability indicates that the score is very close the the group mean, but not exactly the same. A 50 percent probability says the score is exactly between the two group means. The assigned probability is the probability of correct classification. The distinction between it and probability of occurrence is that the former measures how close a score matches a calculated mean, while to determine the latter, one must, in addition , know how close the group mean corresponds to the real geologic environment of the corresponding production category. Therefore, a key assumption in the application of DFA is that the discriminant function does, in fact, correspond mathematically to the geologic factors affecting mineralization. Section 5.2 presents a geologic interpretation of the DFA results. Appendix C presents details about discriminant function analysis.

While the DFA results are useful for a "first cut" classification of mineral potential, there are sources of uncertainty. The fact that a particular cell in the training set contains no reported occurrence of gold does not establish that there are absolutely no gold occurrences in it. Indeed, gold occurrences may be present which are unknown, or

there may be occurrences which are known but not reported. Nevertheless, the lack of reported occurrences defines this particular cell as a "non-occurrence" cell in the training set. In fact, any cell that was either initially defined (in the training set) as a "non-occurrence" cell, or was subsequently classified by DFA as a "non-occurrence" cell, has some likelihood of containing one or more gold occurrences, especially considering the widespread occurrences of gold in trace quantities in most rocks and sediments. Similarly, there is uncertainty concerning a cell which is initially defined or subsequently classified as an "occurrence" cell. Some of the reported occurrences may not be of economic importance in any sense and may have yielded little more than traces of gold. In addition, some reports of the presence of gold may be in error.

The probability estimates of correct classification pertain to each 4 km by 4 km cell as a whole and not to a point or points within the cell. Comparison with the geologic map may suggest that only part of the cell has any actual potential for occurrence. Thus, for appraising a particular cell, the DFA results must be analyzed in the light of the geology in that cell.

Gold

The results for gold indicate that three geologic variables provide a significant contribution to the discrimination process. These are the areal proportion of Precambrian metamorphics (Variable 2); the length of contact between Precambrian granitic rocks and Precambrian metamorphics (Variable 19); and the areal proportion of Mesozoic granitic intrusives or pre-Cenozoic granitic and metamorphic rocks (Variable 11). The variables contributing to the discrimination process are shown in Table 5 with the most effective listed first and the remaining variables in order of decreasing effects in the discrimination process.

A comparison of the correct classifications versus misclassifications in the training set is presented in Table 6 Of the 40 cells in the training set which were defined a priori as "occurrence" cells, 25 (62.5 percent) were correctly classified by DFA, and 15 (37.5 percent) were incorrectly classified. Of the 572 cells in the training set defined a priori as "non-occurrence" cells, 471 (82.3 percent) were correctly classified by DFA, and 101 (17.7 percent) were misclassified.

Table 5

DFA RESULTS FOR GOLD[a]

DFA VARIABLES

Number	Variable Name	F Value[b]
2	Precambrian metamorphics	22.7
19	Contact of Precambrian granite with Precambrian metamorphics	18.1
11	Mesozoic granite and Pre-Cenozoic granite and metamorphics	16.3
13	Tertiary sediments	4.5
37	Length of non-thrust faults	3.3
41	Bouguer gravity	3.2
39	Number of fault intersections	2.8
10	Mesozoic basic intrusives	2.7
20	Contact of Mesozoic granite with Paleozoic sedimentary rocks	2.4
14	Tertiary intrusives	2.1

[a] Geological variables are ranked in decreasing order of their contribution to the discrimination process.

[b] F Value is a measure of the relative contribution of the variable to the discriminant function (77).

Table 6

DFA RESULTS FOR GOLD

Training Cells Correctly and Incorrectly Classified

	Actual	Correctly Classified By DFA	Incorrectly Classified By DFA
Occurrence	40	25 (62.5%)	15 (37.5%)
No Known Occurrence	572	471 (82.3%)	101 (17.7%)
Total	612	496 (81.0%)	116 (19.0%)

As shown in Table 7 only about 5 percent of all reported gold occurrences are in predicted low probability cells. This measure may be slightly biased since the low probability areas may have not been as extensively explored as the high probability areas. Nevertheless, the results offer strong support for using DFA as an indicator of where gold mineralization is not likely to occur.

Copper-Lead-Zinc-Silver DFA Results

Results for combined copper, lead, zinc and silver indicate four or possibly five variables provide significant contribution to the discriminant process. The geological variables that were employed in the DFA are listed in Table 8 with the variables ranked in order of decreasing contribution. The first five variables, Ordovician through Mississipian sediments (Variable 4), contact of Tertiary igneous intrusives with Mesozoic granitic intrusives (32), Precambrian metamorphic rocks (2), Precambrian granitic rocks (1), and Tertiary igneous intrusives (14), contributed most to the DFA's discriminatory power. The various fault relationships, including curvature of faults, contribute very little to the discrimination process.

The results show a number of misclassifications as summarized in Tables 9 and 10. A cell that is classified in the low probability of occurrence category but which has one or more known production occurrences, is misclassified (assuming the report of actual occurrence is correct) and must be regarded as having mineral potential regardless of the DFA results. A cell which receives favorable DFA classification, say 90 percent probability of correct classification in the category consisting of production of $50,000 or more, but which lacks any reported actual production or any known occurrences, is also favorable. But, the degree of certainty that one or more ore deposits are present in such a situation is less than in those cells in which there is absolute certainty that a deposit is present (i.e., where there has been a producing mine).

As shown in Table 10, only about 6 percent of all occurrences of copper, lead, silver and zinc are in cells assigned a low probability of occurrence. The proportion of misclassifications is relatively constant across production categories. This result may be slightly biased since the low probability areas may not have been as extensively explored as high probability areas. Nevertheless, these results provide strong support for the use of DFA as an indicator of where copper, lead, silver and zinc mineralization is not likely to occur.

Table 7

DFA RESULTS FOR GOLD

Known Deposits In Low Probability Cells*

Production Category Of Known Deposit	Number In CDCA	Number In Low Probability Cell (Percentage Of Total)
0	166	3 (1.8%)
1	400	15 (3.7%)
2	172	13 (7.6%)
3	46	7 (15.2%)
4	22	5 (22.7%)
TOTAL	806	43 (5.3%)

* Cells classified as 10 percent or less of probability occurrence.

Production Categories:

0 = Occurrence

1 = Workings, but no production

2 = Production under $50,000

3 = Production between $50,000 and $500,000

4 = Production over $500,000

Table 8

DFA RESULTS FOR COMBINED COPPER-LEAD-ZINC-SILVER[a]

DFA VARIABLES

Number	Variable Name	F Value[b]
4	Ordovician through Mississippian marine sediments	31.2
32	Contact Tertiary intrusives (14) with Mesozoic granite (11)	14.7
2	Precambrian metamorphics	14.1
1	Precambrian granite	13.3
14	Tertiary intrusives	9.4
20	Contact Mesozoic granite (11) with Paleozoic sediments (4 and 5)	6.6
5	Pennsylvanian and Permian marine sediments	5.6
3	Cambrian and Precambrian sediments	4.7
11	Mesozoic granite and pre-Cenozoic granite and metamorphics	4.2
41	Bouguer gravity	3.6
19	Contact Precambrian granite (1) with Precambrian metamorphics (2)	3.3
40	Curvature of faults	2.9
39	Number of fault intersections	2.7
36	Number of thrust faults	1.9

[a] Geological variables are ranked in decreasing order of their contribution to the discrimination process.

[b] F Value is a measure of the relative contribution of the variable to the discriminant function (77).

Table 9

DFA RESULTS FOR COMBINED LEAD, SILVER, ZINC AND COPPER

Training Cells Correctly and Incorrectly Classified

	Actual	Correctly Classified By DFA	Incorrectly Classified By DFA
Production of $50,000 or more	4	3 (75.0%)	1 (25.0%)
Occurrence, but production less than $50,000	52	32 (61.5%)	20 (38.5%)
No Reported Occurrence	556	477 (85.8%)	79 (14.2%)
Total	612	512 (83.7%)	100 (16.3%)

Table 10

DFA RESULTS FOR COMBINED LEAD, SILVER, ZINC, AND COPPER

Known Deposits In Low Probability Cells*

Production Category Of Known Deposit	Number In CDCA	Number In Low Probability Cell (Percentage Of Total)
0	160	11 (6.9%)
1	280	18 (6.4%)
2	148	8 (5.4%)
3	30	1 (3.3%)
4	9	0 (0.0%)
TOTAL	627	38 (6.1%)

* Cells classified as 10 percent or less probability of occurrence.

Production Categories:

0 = Occurrence

1 = Workings, but no production

2 = Production under $50,000

3 = Production between $50,000 and $500,000

4 = Production over $500,000

Iron and Manganese

The DFA results for iron and manganese (see the enclosed map) show that most influential geological variables are the areal proportion of Tertiary igneous intrusives and the areal proportion of Precambrian metamorphics. Contact relationships involving Tertiary igneous intrusives with Tertiary sediments and with Mesozoic granitic intrusives follow in third and fourth place. The geologic variables that were employed in the DFA are listed in Table 11.

The comparison of correct classification versus misclassification of the training cells is presented in Table 12. The proportion of training set cells defined a priori to be in the "occurrence" category and which were misclassified is relatively high (38.5 percent). The misclassification proportion of those training-set cells classified a priori as "non-occurrence" cells is only 8.5 percent.

As shown in Table 13, about 50 percent of iron and manganese occurrences fall in low probability areas. This indicates that the DFA results should not be used to classify areas as having low potential for iron and manganese.

Overall, the DFA results for iron and manganese show weak statistical relationships and the results should be used with caution.

5.2 INTERPRETATION OF THE GEOLOGY

In interpreting the geologic meaning of the DFA results, it is important to stress that DFA yields statistical associations but not geologic reasons for the associations. The statistical relationships do not necessarily connote a cause and effect relationship.

Gold

As Table 5 reveals, gold occurrences in the CDCA are statistically linked with the presence of Precambrian metamorphics, contacts between Precambrian metamorphics and Precambrian granite, and Mesozoic granitic intrusives. In Precambrian metamorphics, the gold may occur in hydrothermal deposits that are related, directly or indirectly, to the presence of granitic intrusives, either of Precambrian or Mesozoic age. While this association is not surprising, it is moderately surprising that the DFA results are so little influenced by the presence of Tertiary igneous intrusives.

Table 11

DFA RESULTS FOR IRON AND MANGANESE[a]

DFA VARIABLES

Number	Variable Name	F Value[b]
14	Tertiary igneous intrusives	25.3
2	Precambrian metamorphics	13.1
34	Contact of Tertiary sediments and Tertiary igneous intrusives	8.5
32	Contact between Tertiary igneous intrusives and Mesozoic granitic intrusives	5.6
15	Tertiary volcanics	3.3

[a] Geological variables are ranked in decreasing order of their contribution to the discrimination process.

[b] F Value is a measure of the relative contribution of the variable to the discriminant function (77).

Table 12

DFA RESULTS FOR IRON AND MANGANESE

Training Cells Correctly and Incorrectly Classified

	Actual	Correctly Classified By DFA	Incorrectly Classified By DFA
Occurrence	13	8 (61.5%)	5 (38.5%)
No Known Occurrence	599	548 (91.5%)	51 (8.5%)
Total	612	556 (90.8%)	56 (9.2%)

Table 13

DFA RESULTS FOR IRON AND MANGANESE

Known Deposits In Low Probability Cells*

Production Category Of Known Deposit	Number In CDCA	Number In Low Probability Cell (Percentage Of Total)
0	55	30 (54.5%)
1	76	33 (43.4%)
2	40	19 (47.5%)
3	4	4(100.0%)
4	3	1 (33.3%)
TOTAL	178	87 (48.9%)

* Cells classified as 10 percent or less probability of occurrence.

Production Categories:

0 = Occurrence

1 = Workings, but no production

2 = Production under $50,000

3 = Production between $50,000 and $500,000

4 = Production over $500,000

Listed below for each of the variables that exerts a significant degree of influence is some rationale for its effect. The variables are discussed in decreasing order of influence.

- Precambrian Metamorphics (Geologic Variable 2)

  The statistical association of this lithologic variable with gold probably reflects several diverse influences. These include; 1, the presence of carbonates (marbles) as reactive host rocks; 2, the presence of gold-bearing quartz veins that occur within schists; and, 3, the presence of disseminated gold incorporated as detrital gold in meta-sedimentary rocks at the time of sedimentation. Some of this originally detrital gold may have been remobilized by hydrothermal processes.

- Contact of Precambrian Granite with Precambrian Metamorphics (Variable 19)

  The association here is not surprising. Classical theory suggests that hydrothermal solutions evaporating from granitic intrusives may be the source of some of the gold present both in the intrusives and in the metamorphics. Intrusive contacts have long been regarded as favorable loci for hydrothermal deposits. Furthermore, the hydrothermal solutions derived from the granitic intrusives may be responsible for remobilization of detrital gold and other forms of disseminated gold.

- Mesozoic Granite and Pre-Cenozoic Granites and Metamorphics (Variable 11)

  The same arguments apply here as above, namely that acidic intrusives, regardless of age, are accompanied by hydrothermal activity.

Examples of the efficacy of these results are given by a survey of the geologic descriptions of gold deposits in Inyo and San Bernardino Counties (summarized in Table C-18). They indicate that many of these deposits accord to some degree to the variables outlined above. Table C-18 shows examples of possible relationships between the geology and the DFA results. These relationships were not verified by field checking. Since the statistical analysis was based on maps at scale 1:250,000, detailed local geology cannot be considered.

Combined Copper, Zinc, Lead and Silver

The geological associations of copper, zinc, lead and silver deposits are markedly different from gold. The DFA results show a close statistical affiliation with the presence of Ordovician through Mississipian sedimentary rocks; contacts of Tertiary igneous intrusives with Mesozoic intrusives; proportions of Precambrian metamorphics, Precambrian granitic rocks, and Tertiary intrusives. The association with the Ordovician through Mississipian marine sediments probably reflects in part, the fact that limestones and dolomites are present and may serve as host rocks.

Contacts between Tertiary and Mesozoic granitic intrusives may have presented favorable situations because of the derivation of ore-forming hydrothermal fluids from the Tertiary intrusives, with both the Tertiary and the Mesozoic intrusives serving as host rocks. Precambrian metamorphics probably serve as host rocks for ore-forming fluids derived from Precambrian intrusives. Thus, overall we seem to detect a close relationship between igneous intrusives (of different ages) and host rocks which include carbonate-bearing Paleozoic sediments, metamorphosed Precambrian sediments, and the various igneous intrusives. All of these associations are compatible with classical theory with respect to the origin of hydrothermal deposits.

The possible role or roles that the principle geologic variables may have played in influencing copper-lead-zinc-silver deposits are described below. The variables are listed in decreasing order of their influence.

- Ordovician Through Mississipian Marine Sedimentary Rocks (Variable 4)

  The principle influence is probably the presence of carbonates which serve as host rocks for hydrothermal solutions.

- Contact Of Tertiary Intrusives With Mesozoic Granite (Variable 32)

  Contact relationships involving acidic intrusive rocks appear to be important ore-forming influences in many contexts such as this one.

- Precambrian Metamorphic (Variable 2)

  These probably serve as host rocks, particularly since carbonates are widely distributed in Precambrian assemblages within the CDCA.

- Precambrian Granite (Variable 1)

  The relationship here is probably partially a contact relationship between younger Precambrian granites and older Precambrian metamorphics.

- Tertiary Intrusives (Variable 14)

  The expanse of Tertiary intrusives, as well as their contact relationships, exert some influence. This is in accord with classical ore-deposit theory.

As examples of the efficacy of these results, Table C-19 lists some of the copper, zinc, lead, and silver mines and prospects in Inyo and San Bernardino Counties and their geologic settings. Table C-19 shows examples of the relationship between the geology and the DFA results. These relationships were not verified by field checking. Since the statistical analyses were based on maps at scale 1:250,000, detailed local geology cannot be considered.

Iron and Manganese

The DFA results for iron and manganese show an association with Tertiary igneous intrusives (Variable 14), Precambrian metamorphics (Variable 2) and contacts between Tertiary igneous intrusives and Tertiary sediments (Variable 34). This suggests that contact metamorphic relationships have considerable bearing. In fact, some of the potential iron and manganese deposits may be of contact metamorphic origin. The iron and manganese deposit in the Palo Verde Mountains in Imperial County are in the presence of Variables 2 and 14 as are the minor manganese deposits in the Randsburg District in San Bernardino County.

6. RECOMMENDATIONS

This geostatistical analysis of G-E-M resources was designed as one of several studies to obtain a "first-cut" classification of the CDCA's potential. However, the data and the intial analyses of this study represent a substantial body of knowledge useful for several purposes. These purposes may require refinement of the present results to meet specific needs. These refinements include the following:

1. Additional geostatistical analyses.
2. Improvement of the data base.
3. Different methods of using the results.
4. Detailed studies of small geographic areas, including field verification.

These are discussed below.

6.1 ADDITIONAL GEOSTATISTICAL ANALYSES

6.1.1 Use of LANDSAT Data

Experience has shown that addition of certain types of data can cause measurable improvement in the results of geostatistical analyses. It is very likely that incorporation of LANDSAT data into the geostatistical routines would result in the following improvements:

- Discriminant function analysis may be attempted for more commodity classes since the "discriminating power" of the variables will be enhanced.
- The results of discriminant function analysis may be more useful since classification errors may be reduced.

LANDSAT Lineament Data

LANDSAT lineament data would very likely cause some measureable improvement in the DFA results. It is probable that there is a genetic relationship between some of the lineaments and the occurrence of ore deposits. Since the Desert Planning Project has the lineament data in hand, this analysis would require only modest effort.

LANDSAT Imagery

Incorporation of numerically encoded LANDSAT imagery into the DFA study would probably yield a substantial improvement in results. The reason for this is that the imagery (quite apart from the lineament analysis) probably incorporates the effects of a variety of processes related to ore deposition, including large-scale hydrothermal rock alteration effects and gossens or other weathering and near surface phenomena.

6.1.2 Refinement of Statistical Analyses

Modifications in the method of applying DFA might result in improvement of results. Some possible modifications are as follows:

- The potential discriminators could be limited to those parameters which can be expected from a geologic standpoint to have relevance to the presence of minerals being studied. Statistical techniques are "blind" in the sense that they recognize numerical relationships but not geologic coincidences of the type that may influence this study. When training cells are taken in large blocks of contiguous area, geologic associations peculiar to one area tend to be extrapolated to cells where such anomalies are absent. Prudent elimination of variables unlikely to be meaningfully correlated with the minerals in questions may improve the discriminant function's performance in areas outside the training cells.

- DFA discriminates between populations at the midpoint between their discriminant function means. Although this is a common choice in cases where there is no clear preference of another value, it carries two tacit assumptions. First, it assumes that the populations have the same variances and a priori probabilities; and second, it assumes equal costs of misclassifying the two populations. These assumptions should be questioned. For example, it may be preferable to misclassify cells where minerals are known to occur rather than those where minerals do not occur. If so, it may be more useful to draw the discriminating line closer to the mean of the occurrence population.

- An analysis using different training sets and different occurrence categories may be useful.

6.1.3 Use of Additional Data

In any statistical study, additional relevant information improves results. Additional data sources are suggested in Section 6.2 below. The following information would be useful.

- Additional G-E-M occurrence information--especially data from producers or the Bureau of Mines questionnaire.
- Consistent, uniform aeromagnetic data for the CDCA.
- Geochemical sampling results.
- Results of radiometric surveys.
- Results of vegetation surveys.

6.2 IMPROVEMENT OF THE DATA BASE

The data bases developed for this project are designed to allow editing or additional information with little effort or cost. Some possible improvements in the data base are the following.

6.2.1 Bureau of Mines Questionnaire

These questionnaires probably contain accurate information regarding production of G-E-M resources. The Bureau of Mines considers the data to be proprietary because the organizations completing the questionnaire were promised that the information would be kept confidential. Some of the data can be released by the Bureau of Mines if either the respondent did not request confidentiality when completing the form, or if the respondent subsequently approves release of the information. Thus, BLM could gain access to at least some of these data.

6.2.2 Data From Producers

BLM may be able to obtain additional occurrence information by requesting it from producers. This may be accomplished either by sending questionnaires directly to producers (after approval by OMB) or by soliciting information through trade associations.

6.2.3 Aeromagnetic Data

Uniform and complete aeromagnetic data covering the CDCA might improve the results. Presently available data are not useful for geostatistical purposes since they were obtained at different times by different organizations, flying at different altitudes with different equipment, and using differing data reduction assumptions. For geostatistical purposes, it is necessary to have aeromagnetic surveys that are uniform in quality.

6.2.4 Geochemical and Radiometric Surveys

Several ongoing geochemical and radiometric surveys may provide additional data. These include the sampling programs for the NURE Program of the Department of Energy and geochemical reconnaissance surveys being conducted by USGS. Results of these surveys could be readily entered into the data base.

6.3 METHODS FOR USING RESULTS

This report represents a massive data collection and analysis project. For reporting purposes, the data and results were condensed and summarized based on the perceived needs of the Desert Planning Staff. It is likely that alternative ways of tabulating and presenting the results may be useful. Two suggestions are as follows.

1. Plotting

   Using the SURFACE II plotting routine, it is possible to plot, at any scale, any information in the data base. For example, it may be desirable to plot the location of all sand and gravel pits in San Bernardino County. Use of SURFACE II for this purpose is fast and relatively inexpensive.

2. Data Listings

   Using the data base, it is possible to produce lists according to any desired criteria. For example, the computer can produce a listing of all gold occurrences by county and by production category.

3. Composite Map

   Using the DFA results and reported occurrences for individual commodity categories, a composite map showing areas of high potential and low potential for mineralization could be prepared. This might facilitate decisions on land use.

6.4 DETAILED STUDIES OF SMALL GEOGRAPHIC AREAS

The current project is viewed as a G-E-M resource reconnaissance evaluation. Grid cell size is 2 km x 2 km and the basic map is 1:250,000 scale. As the Desert Planning Staff focuses on smaller areas within the CDCA, it is possible to conduct a statistical evaluation of G-E-M resources in far greater detail. Cell size could be reduced to 1 km x 1 km or 500 m x 500 m assuming that geologic maps at a scale of 1:24,000 or greater are available. At this level of evaluation, it would be useful to include information from other Desert Planning Project studies as part of the G-E-M evaluation. For example, the inclusion of data on vegetation complexes would allow geobotanical statistical studies.

In evaluating a smaller area, field verification may be required for geologic interpretation and verification of mineral occurrence information. Use of conventional aerial photographs or SKYLAB photographs also may be useful.